Landsat-7 Level-0 and Level-1 Data Sets Document

Summary:

The launch of the Landsat-7 satellite on April 15, 1999 marks the addition of the latest satellite to the Landsat satellite series. The Earth Resources Technology Satellite (ERTS) Program launched the first of a series of satellites (ERTS 1) in 1972. Part of the National Aeronautics and Space Administration's (NASA) Earth Resources Survey Program, the ERTS Program and the ERTS satellites were later renamed Landsat to better represent the civil satellite program's prime emphasis on remote sensing of land resources. Landsats 1, 2, and 3 carried the multispectral scanner (MSS) sensor and experimental return beam vidicon cameras. The Landsat-4 satellite carried the MSS and thematic mapper (TM) sensors, as does the still currently flying Landsat-5 satellite. The sixth satellite in the Landsat series was unsuccessfully launched and did not achieve orbit. The Landsat-7 satellite carries the enhanced thematic mapper plus (ETM+) sensor. The launch of the Landsat-7 satellite is part of an ongoing mission to provide quality remote sensing data in support of research and applications activities.

Acknowledgment:

Thank you to the National Oceanic and Atmospheric Administration (NOAA), NOAA/National Environmental Satellite, Data, and Information Service, and to NASA for their roles in the cooperative effort to prepare this document.

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1. Data Set Overview:

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- Landsat-7 Level-0 WRS Data Collections
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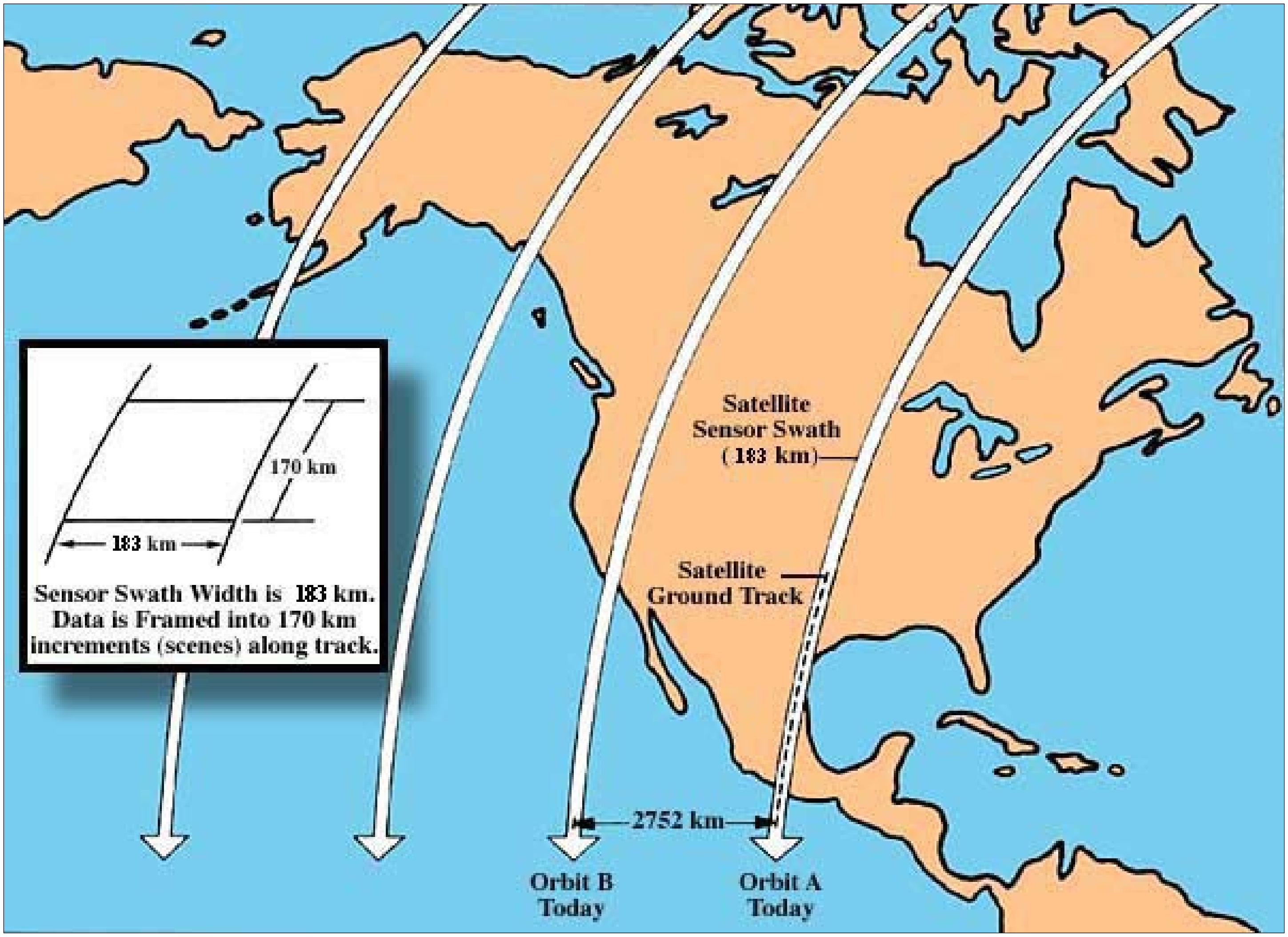
Data Set Introduction:

The Landsat-7 system is another step in the development and application of remotely sensed satellite data for use in managing the Earth's land resources. As with earlier Landsat systems, the Landsat-7 platform, along with its enhanced thematic mapping sensor, provides for new capabilities in remote sensing of the Earth's land surface.

Landsat-7 data are collected from a nominal altitude of 705 kilometers in a near-polar, near-circular, sun-synchronous orbit at an inclination of 98.2 degrees, imaging the same 183-km swath of the Earth's surface every 16 days.



The orbital pattern equates to a 233-orbit cycle with a swath sidelap that varies from approximately 7 percent at the equator to nearly 84 percent at 81 degrees north or south latitude.

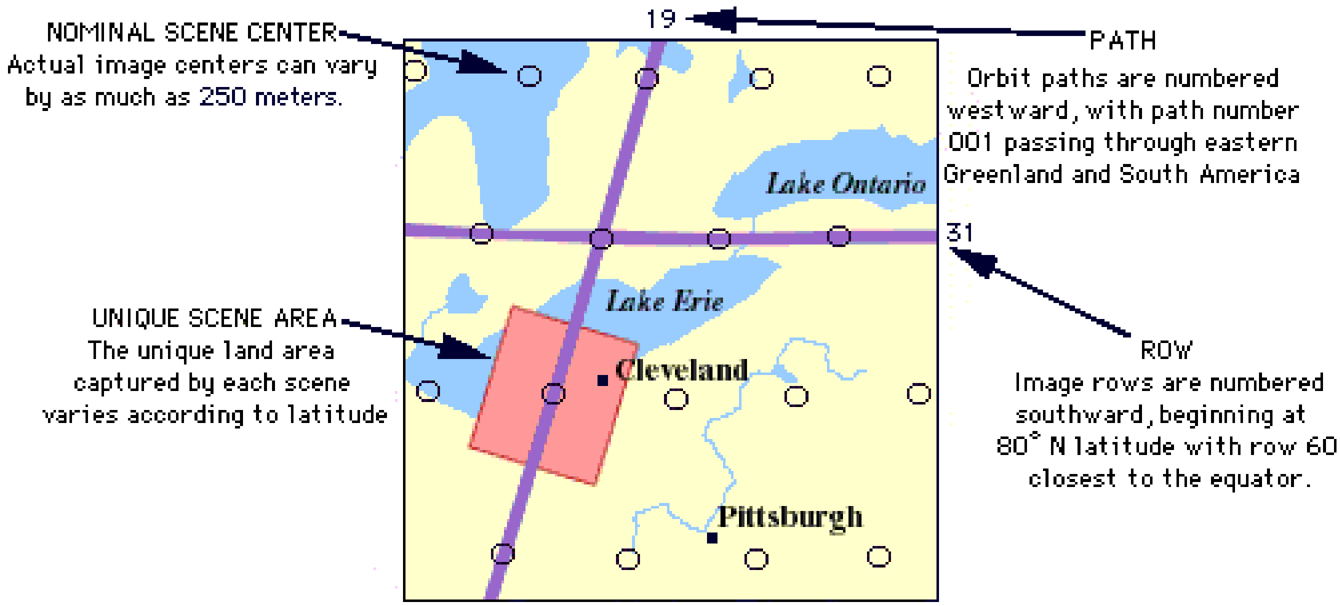
Table 1. Image Sidelap of Adjacent Swaths

Latitude(°)	Image Sidelap (%)
0	7.3
10	8.7
20	12.9
30	19.7
40	29.0
50	40.4
60	53.6
70	68.3
80	83.9

The equatorial crossing times for the Landsat-7 satellite are the same as for the Landsat-4 and Landsat-5 satellites (i.e., the sun-synchronous orbit of the Landsat satellites implies that each pass over local latitudes takes place at approximately the same local-solar time each day).

The Landsat-7 satellite is to share its orbit configuration with NASA's Earth Observing System (EOS) Terra satellite. Plans are for the two satellites to be placed in identical orbits, ideally 15 minutes apart from each other, with the Terra satellite in a follow-on orbit to the Landsat-7 satellite. The end result is repetitive data coverage, while such variables as plant physiology are under nearly identical conditions.

The Landsat scenes are mapped to a global notation system called the Worldwide Reference System (WRS), annotating the nominal scene center of Landsat imagery using Path and Row designators that equate to the satellite's 233-orbit cycle. Following is a portion of a WRS path/row map showing scene coverage over Cleveland, Ohio:



The Landsat-7 satellite's payload includes the ETM+ sensor. The ETM+ sensor is an enhanced version of the TM sensor flown aboard the Landsat-4 and -5 satellites, but most closely approximates the ETM sensor lost on board the Landsat-6 satellite. Sensor enhancements include the addition of the panchromatic band and two gain ranges, which improved spatial resolution for the thermal band, and the addition of two solar calibrators.

The ETM+ sensor is designed to collect, filter, and detect radiation from the Earth in a 183-kilometer swath as it passes overhead, providing the necessary cross-track scanning motion while the Landsat-7 spacecraft's orbital motion provides an along-track scan. Daytime data are collected during the satellite's descending mode, while nighttime data are collected during the satellite's ascending mode.

Spectral bandwidths for the ETM+ sensor are determined through the combined response of all the system's optical path mirrors (e.g., primary, secondary, scan line corrector), spectral filters, and individual detectors. The spectral filters, located immediately in front of each detector array, predominately establish the optical bandpass for each spectral band. The filter housing for the prime focal plane contains filters for bands 1 through 4 and for band 8 (the panchromatic band). The filter housing for the cold focal plane assembly contains filters for bands 5 through 7. Following is a comparison of bandwidths between the TM sensor flown aboard the Landsat-4 and -5 satellites and the ETM+ sensor flown aboard the Landsat-7 satellite:

Table 2. TM and ETM+ Spectral Bandwidths

Band width (μ) Full width – Half maximum								
Sensor	Band1	Band 2	Band 3	Band 4	Band 5	Band 6	Band 7	Band 8
TM	0.45 - 0.52	0.52 - 0.60	0.63 - 0.69	0.76 - 0.90	1.55 - 1.75	10.4 - 12.5	2.08 - 2.35	N/A
ETM+	0.45 - 0.52	0.53 - 0.61	0.63 - 0.69	0.78 - 0.90	1.55 - 1.75	10.4 - 12.5	2.09 - 2.35	.52 - .90

A discrete spectral shift that occurred with the Landsat-5 TM sensor has been attributed largely to filter outgassing. Steps have been taken to make the ETM+ sensor more resistant to this phenomenon. In addition, filters on the ETM+ sensor have shown significant improvement in band-edge responses as compared to the filters in the TM sensor flown aboard the Landsat-4 and -5 satellites.

Objective/Purpose:

Landsat-7 mission objectives include:

- Maintaining Landsat data continuity by providing data that are consistent in terms of data acquisition, geometry, spatial resolution, calibration, coverage characteristics, and spectral characteristics with previous Landsat data.
- Generating and periodically refreshing a global archive of substantially cloud-free, Sun-lit, landmass imagery.
- Continuing to make remote sensing satellite data available to domestic and international users and expanding the use of such data for global change research in both the Government and private commercial sectors.
- Promoting interdisciplinary research via synergism with other EOS observations, in particular, orbiting in tandem with the Terra satellite for near coincident observations.

Summary of Parameters:

Table 3. Nominal orbit parameters for the Landsat-7 spacecraft include:

Parameter	**Value**
Launch Date:	April 15, 1999
Orbit:	Sun Synchronous, Near Polar 705 Kilometers, Near Circular
Inclination:	98.2 Degrees
Nodal Period:	98.8 Minutes
Equatorial Crossing Time:	10:00 a.m., Local (Descending)

Discussion:

Data collected by the ETM+ sensor flown aboard the Landsat-7 satellite are in a raw format, meaning that radiometric and geometric corrections have not yet been applied to the data. Data collected in their raw format are level-0 data and equate to a Landsat-7 level-0R product. The level-0R product contains all of the ancillary data required to perform radiometric and geometric corrections, including a calibration parameter file that is generated by the Landsat-7 Image Assessment System (IAS).

When a Landsat-7 level-0R product is radiometrically corrected, it is referred to as a level-1R product (i.e., level-1 data). Radiometric correction is performed either by using gains computed on the fly by the internal calibrator or by using gains available in the calibration parameter file. No geometric corrections are applied to the level-1 data so the geometry of the level-1R product is the same as for the level-0R product (i.e., raw or level-0 Landsat-7 ETM+ sensor data).

When a Landsat-7 level-0R product is both radiometrically and geometrically (i.e., systematically) corrected, it is referred to as a level-1G product (i.e., still level-1 data). Correction algorithms model the spacecraft and the sensor, using data generated by onboard computers during imaging events. During processing, level-0 image data undergo two-dimensional resampling according to user-specified parameters, including output map projection, rotation angle, pixel size, and resampling kernel. Seven map projections are supported, including: (1) Universal Transverse Mercator, (2) Lambert Conformal Conic, (3) Transverse Mercator, (4) Polyconic, (5) Oblique Mercator, (6) Polar Stereographic, and (7) Space Oblique Mercator. A level-1G product is a geometrically rectified product that is free from distortions related to the satellite platform (e.g., attitude deviations from nominal), the sensor (e.g., jitter, view-angle effects), and global Earth characteristics (e.g., rotation, curvature). Distortions due to the Earth's terrain are still present.

The systematic level-1G correction process does not employ ground control or relief models to attain absolute geodetic accuracy. Residual error in the systematic level-1G product is approximately 250 meters (1 sigma) in flat areas at sea level. Precision correction employs ground control points to reduce geodetic error of the output product to approximately 30 meters. This accuracy is attainable in areas where relief is moderate. Terrain correction processing that employs both ground control points and digital elevation models can further reduce the geodetic error of the output product to less than 30 meters in areas where terrain relief is substantial.

Related Data Sets:
Since the 1970's, Landsat satellites have been collecting multispectral images of the Earth's land surface. This unique data archive has played an important role across disciplines as a tool used toward achieving improved understanding of the Earth's land surfaces and human impacts on the environment. Landsat satellite orbital paths, sensors, and communications capabilities have changed over the years as the Landsat program continues to evolve (see Table).

Table 4. Landsat Satellites 1-7

System	Launch (End of Service)	Sensor	Resolution (meters)	Communications	Alt. (Km)	R (Days)	D (Mbps)
Landsat 1	07/23/72 (01/06/78)	RBV MSS	80 80	Direct downlink with recorders	917	18	15
Landsat 2	01/22/75 (02/25/82)	RBV MSS	80 80	Direct downlink with recorders	917	18	15
Landsat 3	03/05/78 (03/31/83)	RBV MSS	40 80	Direct downlink with recorders	917	18	15
Landsat 4*	07/16/82	MSS TM	80 30	Direct downlink TDRSS	705	16	85
Landsat 5	03/01/84	MSS TM	80 30	Direct downlink TDRSS**	705	16	85
Landsat 6	10/05/93 (10/05/93)	ETM	15 (pan) 30	Direct downlink with recorders	705	16	85
Landsat 7	04/15/99	ETM+	15 (pan) 30 60	Direct downlink with recorders (solid state)	705	16	150

Alt. = Altitude
R = Revisit Interval
D = Data Rate
- TM data transmission failed in August 1993

** Current data transmission by direct downlink only. No recording capability.

Whether as part of the primary collection effort or as part of a follow-on project, there are a variety of complementary Landsat-related data sets. Some of these data sets are listed below:
COMPLEMENTARY DATA SETS

*NASA EDC DAAC Data Sets**
Global Land Cover Test Sites Data (Landsats 1-5)
NASA Landsat Data Collection (Landsats 1-5)
North American Landscape Characterization Data (Landsats 1-5)

*USGS Data Sets***
Landsat Multispectral Scanner Data (Landsats 1-5)
LGSOWG Multispectral Scanner Data (Landsats 1-5)
Landsat Thematic Mapper Data (Landsats 4-5)
LGSOWG Thematic Mapper Data (Landsats 4-5)
*EDC DAAC Data Inventories Search Engine
(http://edcimswww.cr.usgs.gov/pub/imswelcome/)
**USGS Data Inventories Search Engine
(http://edcwww.cr.usgs.gov/webglis)

2. Applications:

Landsat data have been used in both national and international arenas for a variety of government, public, and private applications, including land and water management, global change research, oil and mineral exploration, agricultural yield forecasting, pollution monitoring, land surface change detection, and cartographic mapping.

As part of NASA's EOS project, the science mission of the Landsat-7 project is targeting regional and global assessments of land cover dynamics. The Landsat-7 satellite is scheduled to systematically acquire imagery from across the globe, using a
Long-term Acquisition Plan. The Plan is designed to insure coverage of full seasonal and interannual changes in planetary vegetation patterns, also addressing the issue of cloud cover.

Following are examples of research projects using Landsat data:

Dune Reactivation (Goetz): More than 10 percent of the High Plains region of the United States consists of sand dunes and sand sheets that are stabilized by the growth of natural grasses and by irrigated farming. According to some climate models, sandy landscapes could be reactivated (i.e., start blowing as was the case in the 1930's). Using Landsat data, Goetz and his team have completed a detailed study of land cover change in northeastern Colorado, creating a data base of land cover and human-induced land cover changes in the region that spans 15 years. With data from Landsat 7, Goetz plans to extend the data base past the year 2000. It is expected that it will be possible to catch a significant drought year, which will help to validate models on the effect of low rainfall in the High Plains.

Gradual Changes in the Antarctic Ice Sheet (Bindschadler): The stability of the West Antarctic Ice Sheet directly correlates to increases in the global sea level. Monitoring changes in the ice sheet is difficult from the ground, because dangerous conditions prohibit the collection of extensive measurements. Bindschadler and his team used Landsat data to analyze surface features on the Ross Ice Shelf, a vast area of ice that is attached to Antarctica but that is floating on the ocean, in order to study the history of ice flows over much of West Antarctica. The team plans to use Landsat-7 data with its finer spatial resolution and continuous spatial coverage to monitor the continued ice motion and flow history of this Antarctic ice sheet.

Growth Patterns of Urban Sprawl (Masek): Studies using Landsat data can show where growth is taking place in urban areas and can be used as a tool by geographers in evaluating the possible effects of urban planning programs on population growth and land use. Masek and colleagues use Landsat data to study land use efficiency. They plan to use Landsat-7 data to evaluate growth patterns in cities around the world. With more satellite imagery available, it is possible to compare cities more frequently in order to compile records of land use changes in greater detail.

Health of Temperate Conifer Forests (Woodcock): Both natural and human activities may lead to the destruction of forests and their ecosystems. Woodcock discovered that with Landsat data he could recognize areas where trees were dying due to lack of water, a factor that made the trees more susceptible to disease and forests more susceptible to fire. Woodcock and colleagues plan to use Landsat-7 data to create a global monitoring system for temperate conifer forests.

Land Use in Tropical Rain Forests (Skole): Even though tropical deforestation is a well-known problem, scientists face the problem of determining deforestation rates and of understanding their causes and effects. Currently, Skole's team is analyzing Landsat-5 imagery in order to develop estimates of recent tropical deforestation. With the launch of the Landsat-7 satellite, the amount of data available for analyses such as these increases dramatically, allowing for more rapid assessment of land use and land cover change.

Mapping Wildfire Hazards (van Wagtendonk): Wildland fires result in loss of life and in damage to natural resources. Dry biomass on the ground acts as a fuel in feeding wildland fires. With information about fire fuels, fire managers can better predict potential fire behavior, make more informed tactical and strategic decisions, and introduce treatments that reduce the amount of dry biomass. Van Wagtendonk and colleagues use Landsat data in time series, identifying fuel types based on seasonal changes in plant condition. The addition of a panchromatic Landsat band enhances the capability to distinguish tree density classes -- an important development, because density directly affects fuel moisture content and wind speeds near the ground.

Precision Farming and Land Management (Moran): Farm managers are looking for new technologies to help in deciding when and where to irrigate, fertilize, seed, and apply herbicides. In a method developed by Moran, Landsat data are combined with radar data to study plant transpiration rates, information that managers use to determine where and when to fertilize. The increased availability of satellite data through the launch of the Landsat-7 satellite provides for expanded applications of remote sensing data to agricultural and natural resources monitoring projects.

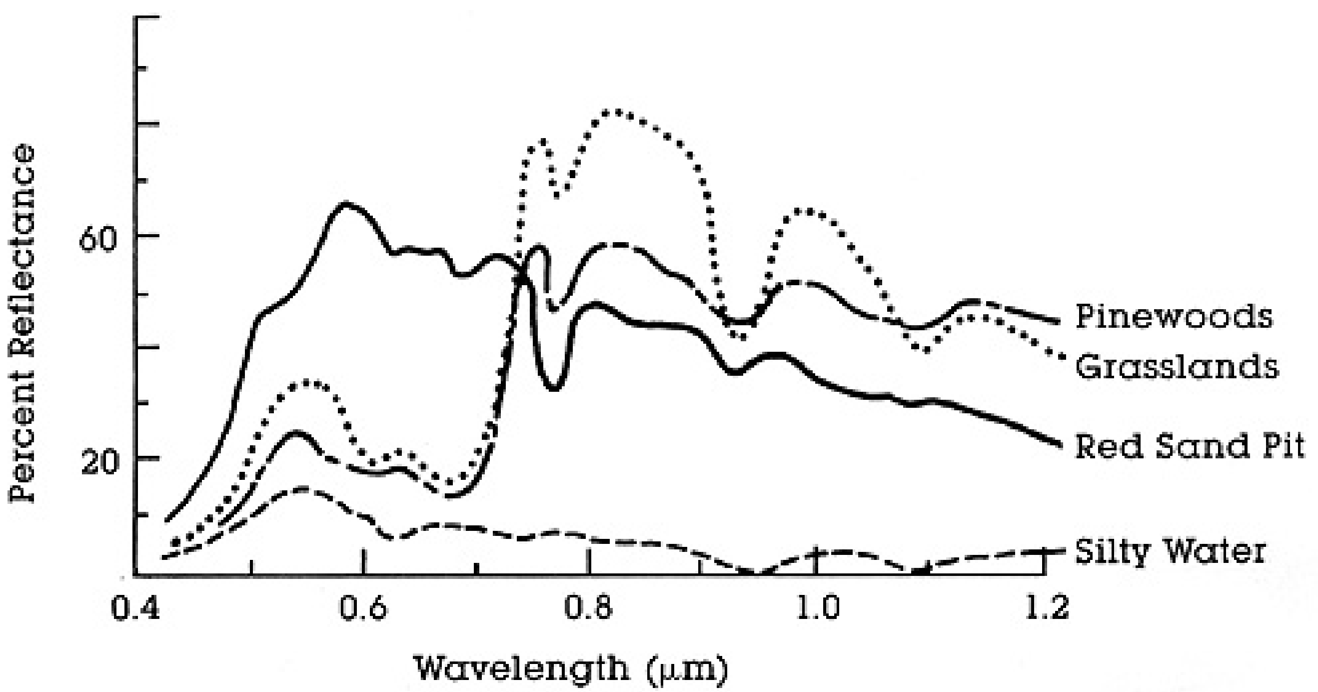
Spring Run-off Contaminants in Lakes (Schott): In the spring, run-offs of salt, sediment, fertilizer, and chemical pollutants concentrate in a small band of warmer water close to the lake shore, called a thermal bar, until the warm run-off waters and the cold lake waters have had an opportunity to mix. In larger lakes, it may take up to two months for the run-off and lake waters to mix, posing a potential danger to lake plants and animals (e.g., phytoplankton, fish). Schott uses Landsat data to help predict the extent, duration, and impacts of thermal bar formations on water quality. Schott and his research team model the formation of thermal bars, using Landsat data and three-dimensional hydrodynamic models. Schott plans to use the models to track the annual evolution of thermal bars and to attempt the prediction of thermal bars months in advance of their formation.

Volcanic Hazards and Lava Lakes (Flynn): Using Landsat data to observe heat emitted during volcanic eruptions, Flynn is able to distinguish active lava flows from older lava flows that have already begun to cool. After compiling extensive observations of individual volcanoes, a data base is created that details areas that are the most prone to the hazards of lava flows. Flynn and colleagues also have been using Landsat data to study active volcanic lava lakes from around the world. In addition to the maps they have already generated using Landsat data, they plan to produce higher resolution maps of active lava flows using Landsat-7 data.

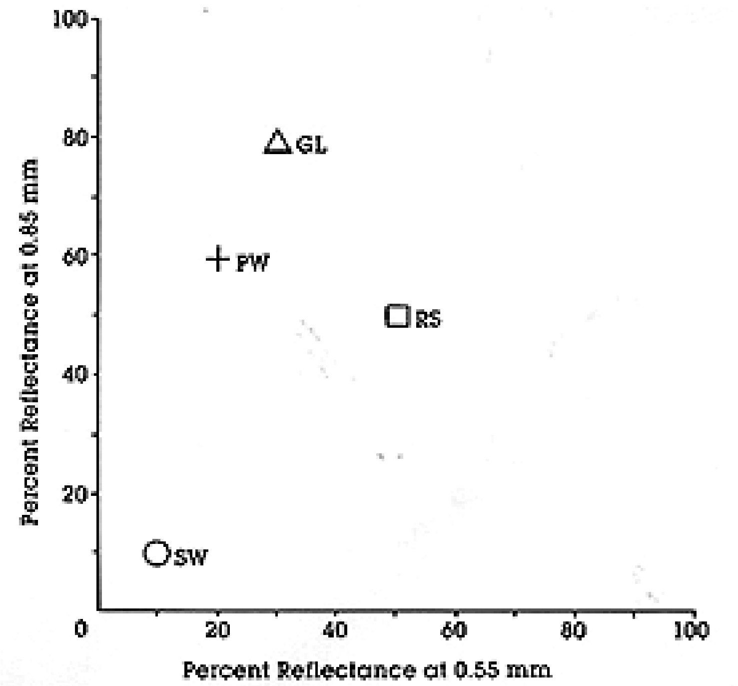
3. Theory of Measurements:

On striking the atmosphere, land surface, or ocean surface, transmitted solar radiation is characterized as one of three types of energy response:
Absorption: Radiation which is absorbed through electron or molecular reactions within the medium encountered. A portion of the energy incorporated can then be re-emitted (as emittance), largely at longer wavelengths, so that some of the Sun's radiant energy engages in heating the target, giving rise to a thermal response.

Reflectance: Radiation which is, in effect, being reflected (and scattered) away from the target at different angles (depending in part on surface roughness as well as on the angle of the Sun's direct rays relative to surface inclination), and some radiation being directed back on line with the observing sensor.
Transmittance: Radiation which penetrates into certain surface media such as water.
The Landsat-7 system is designed to measure reflected radiation; data that, in turn, are used to deduce surface conditions and materials. For any given material, the amount of emitted and reflected radiation varies by wavelength. Therefore, substances or classes of ground cover may be identified and separated by their spectral signatures as shown in the figure below.



There is a direct correlation between objects and their relative reflectances. For example, the reflected radiation from healthy green growing vegetation may be highly visible in one wavelength or spectral band while the same reflected radiation may be barely visible, if visible at all, in another wavelength or spectral band. Thus, in principle, various surface materials may be recognized and distinguished from each other through differences in relative reflectances, provided there is some suitable method for measuring these differences as a function both of wavelength and of intensity of returned radiation (as a fraction or percent of the amount of the irradiating radiation). The four surface materials shown in the following figure (GL representing grasslands, PW representing pinewoods, RS representing red sand, and SW representing silty water) may be characterized as distinct.

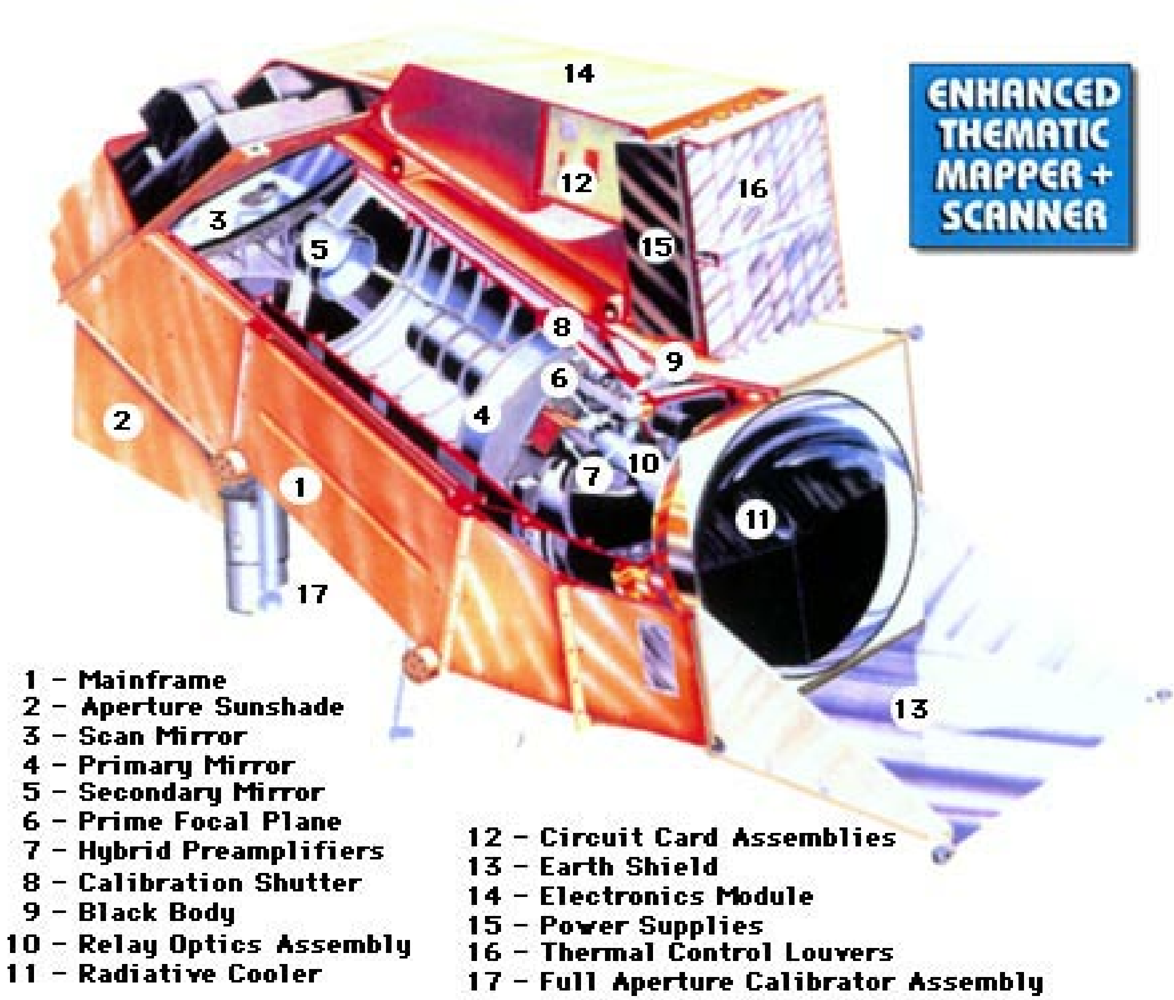


Each of the materials has been plotted according to its percent of reflectance for two wavelengths or spectral bands. When more than two wavelengths are involved, the plots in multi-dimensional space tend to increase the reparability among different materials. This spectral separation is the basis for the multispectral remote sensing employed by the ETM+ sensor flown aboard the Landsat-7 satellite.

4. Acquisition Materials and Methods:

Acquisition Equipment:
Landsat ETM+ sensor flown aboard the Landsat-7 satellite

Sensor/Instrument Description:
The Landsat ETM+ sensor is a nadir-viewing, eight-band multispectral scanning radiometer capable of providing high-resolution imaging information of the Earth's surface. The sensor is a derivative of the TM sensor flown aboard Landsat satellites 4 and 5 with modifications that include the addition of the panchromatic band and two gain ranges, improvements to the spatial resolution of the thermal band, and the addition of two solar calibrators. Principle sensor components include the scan mirror assembly, a Ritchey-Chretien telescope, a scan line detector, the primary focal plane, relay optics, the cold focal plane, a radiative cooler, and spectral filters (see Sensor/Instrument Measurement Geometry below for more information on these components).



Collection Environment:
Satellite Platform.
Source/Platform:

The Landsat-7 satellite was built by Lockheed Martin Missiles & Space Company, Inc., at their Valley Forge, Pennsylvania, facility and was launched on April 15, 1999, from the Western Test Range, Vandenberg Air Force Base, California. The spacecraft is 14 feet long, 9 feet in diameter, and weighs approximately 4,800 pounds.

Landsat-7 spacecraft.

The Landsat-7 satellite is designed to fly a 705-kilometer, Sun-synchronous, Earth mapping orbit with a 16-day repeat cycle. Its payload is a single nadir-pointing instrument, the ETM+ sensor. Communications are provided through the satellite's S-band and X-band. The S-band is used for command and housekeeping telemetry operations while the X-Band is used for instrument data downlink. A 378-gigabit solid state recorder can hold 42 minutes of instrument data and 29 hours of housekeeping telemetry, concurrently. Power is provided by a single Sun-tracking solar array and two 50-amp-hour, nickel-hydrogen batteries. Attitude control is provided through four reaction wheels (pitch, yaw, roll, and skew), three 2-channel gyros with celestial drift updating, a static Earth sensor, a 1750A processor, and torque rods and magnetometers for momentum unloading. Orbit control and backup momentum unloading is provided through a blow-down monopropellant hydrazine system with a single tank containing 270 pounds of hydrazine, associated plumbing, and twelve 1-pound-thrust jets.

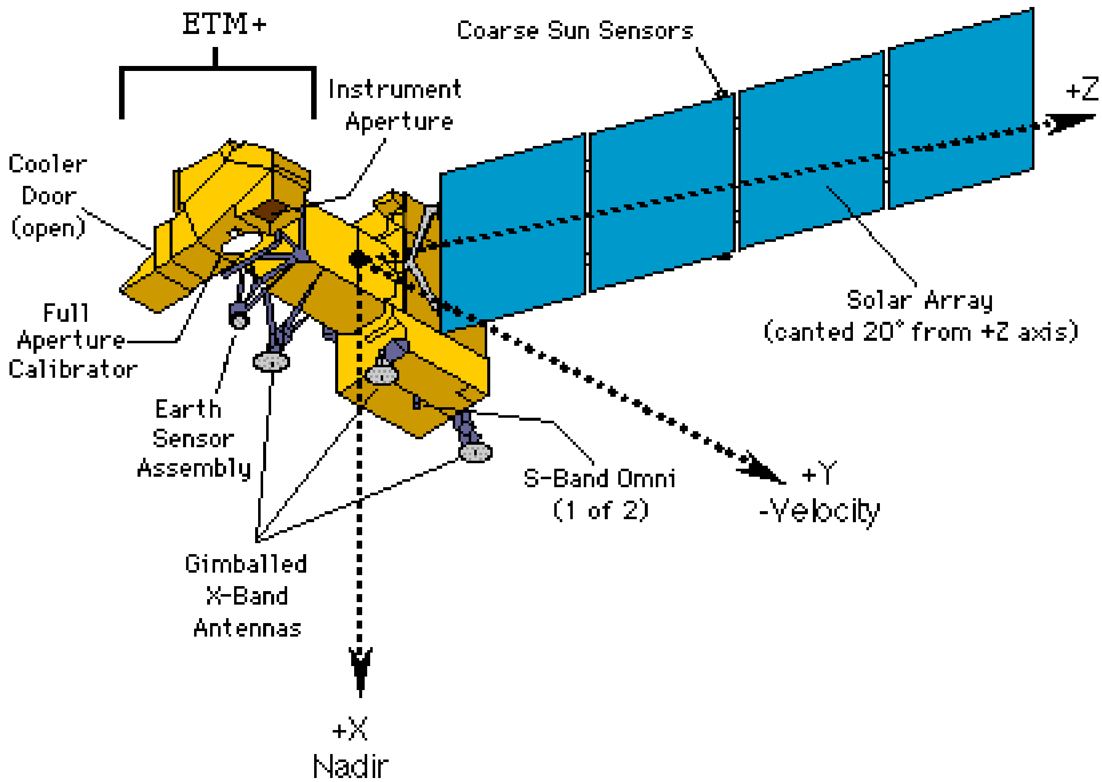


Diagram of Landsat-7 satellite components.

Satellite subassemblies include:

Lower Equipment Module: This module is a secondary structure for equipment. In addition, a payload attach fitting is mounted on the aft end of this module, providing structural and electrical interfaces to the launch vehicle, a Boeing Delta-II rocket.
Equipment Support Module: This module houses equipment requiring a uniform temperature environment.
Instrument Pallet Assembly: This module is used for mounting the ETM+ sensor.
The structural subassemblies accommodate seven functional subsystems, including the command and data handling subsystem, the attitude control subsystem, the reaction control subsystem, the electrical power subsystem, the thermal control subsystem, the communication subsystem, and the ETM+ payload.

Source/Platform Mission Objectives:
The latest in the Landsat series, the Landsat-7 satellite is to provide a vehicle for continuing the flow of global change information to users worldwide. The Landsat-7 satellite fulfills its mission by providing repetitive, synoptic coverage of continental surfaces and by collecting data in spectral bands that include the visible, near-infrared, shortwave, and thermal infrared portions of the electromagnetic spectrum.

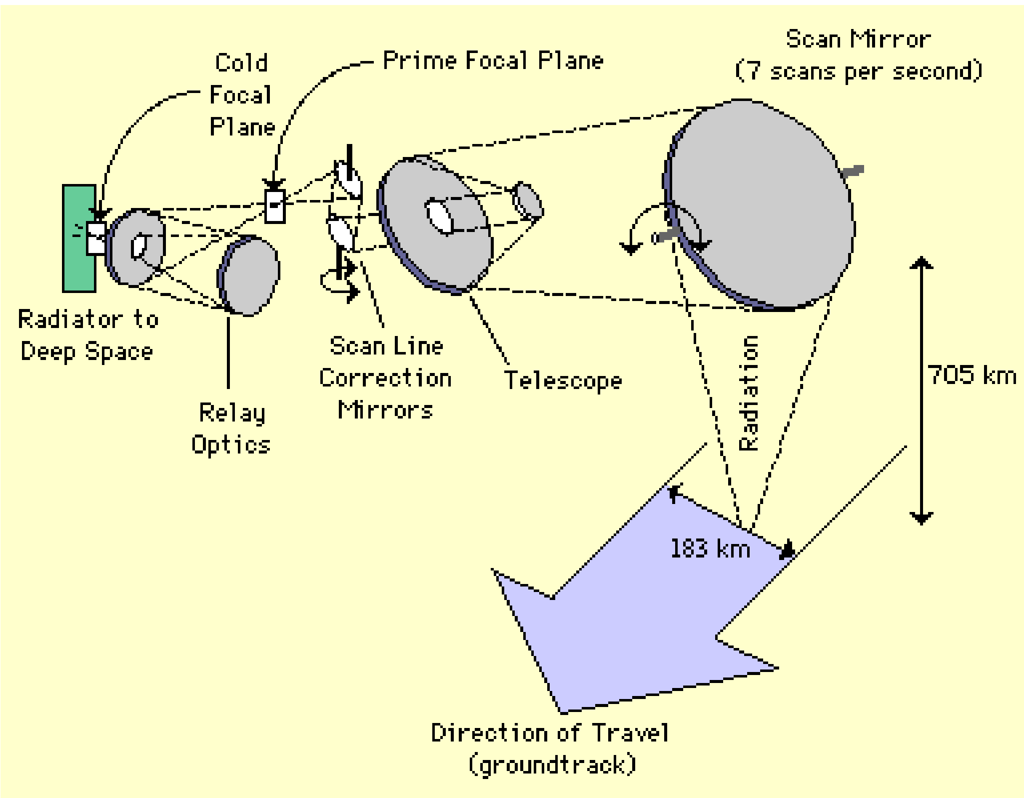
Key Variables:

- Emissivity
- Infrared Imagery
- Land Cover
- Reflectance
- Reflected Infrared
- Thermal Infrared
- Visible Imagery

Principles of Operation:
The Landsat ETM+ sensor is a nadir-viewing, eight-band multispectral scanning radiometer that detects spectrally filtered radiation from several portions of the electromagnetic spectrum while orbiting the Earth from an altitude of 705 kilometers. Nominal ground sample distances or pixel sizes include 30 meters each for the six visible, near-infrared, and shortwave infrared bands, 60 meters for the thermal infrared band, and 15 meters for the panchromatic band. The ETM+ sensor is designed to produce approximately 3.8 gigabits of data for each Landsat scene.

Sensor/Instrument Measurement Geometry:
The Landsat ETM+ sensor operates from a 3-axis, stabilized satellite platform. With the platform traveling in a near-polar, Sun-synchronous, near-circular orbit at an altitude of 705 kilometers and an inclination of 98.2 degrees, the ETM+ sensor is designed to collect, filter, and detect radiation from the Earth in 183-kilometer swaths. The ETM+ sensor provides the across-track scanning capability in east-to-west and west-to-east directions while the orbital path of the Landsat-7 satellite platform provides the along-track capability in a north-south direction.

Energy reflected from the Earth's surface passes through several ETM+ subsystems before being collected by the solid-state detectors at the focal plane.



A bidirectional scan mirror assembly sweeps the detector's line of sight in the across-track directions. A Ritchey-Chretien telescope focuses the energy onto a pair of motion-compensation mirrors (i.e., a scan line corrector) where the energy is redirected to the focal planes. The scan line corrector is required, because there is significant overlap and underlap in ground coverage between successive scans due to the compounded effect of along-track and cross-track motion.

The then aligned energy encounters the primary focal plane, where the silicon detectors for bands 1 through 4 and band 8 are located. A portion of that energy is redirected by relay optics from the primary focal plane to the cold focal plane, where the detectors for bands 5 through 7 are located. The temperature of the cold focal plane is regulated by a radiative cooler. The spectral filters for the bands are located directly in front of their respective detectors.

Manufacturer of Sensor/Instrument:
Raytheon Santa Barbara Remote Sensing, Santa Barbara, California.
Calibration:
Specifications:
Pre-Launch Radiometric Calibration: Reflective Band Calibration and Monitoring. Two spherical integrating sources (SIS) were used to calibrate the ETM+ sensor prior to launch. The first SIS, a 100-centimeter source (SIS100), is equipped with eighteen 200-watt lamps, six 45-watt lamps, and ten 8-watt lamps, thus, providing radiance levels covering the full dynamic range of the instrument in all bands and at least 10 useable radiance levels for each band for each gain state. The SIS100 was used to perform the primary radiometric calibration of the ETM+ sensor in August 1997 and also was used for the pre-launch calibration of the Terra satellite's Moderate Resolution Imaging Spectroradiometer sensor.

The second source, a 122-centimeter source (SIS48), is equipped with six 200-watt lamps, two 100-watt lamps, and four 25-watt lamps. The SIS48 was used for monitoring the radiometric calibration of the ETM+ sensor five times during instrument- and spacecraft-level testing. During SIS calibrations, the bench test cooler was used to maintain the temperature of the cold focal plane at 105 degrees. This was the only one of the three temperature set points for the cold focal plane that could be obtained under ambient pressure and temperature conditions.

The calibration data reduction is performed as follows:
(1) ETM+ band spectral radiances (Ll,b,s), for band "b", and sphere level "s", are calculated as:

(1) The ETM + band weighted spectral radiances, $L_\lambda(b,s)$, for band "b" and sphere level "s" are calculated as:

$$L_\lambda(b,s) = \frac{\int RSR(b,\lambda) L_\lambda(s,\lambda) d\lambda}{\int RSR(b,\lambda) d\lambda}$$

Where:

$RSR(b,\lambda)$ is the Relative Spectral Response for band "b" at "λ" calculated from component level transmission, reflectance and responsivity measurements,

$L_\lambda(s,\lambda)$ is the measured spectral radiance of sphere level "s" at "λ"

(2) The quantized detector (d) by detector responses, $Q(d,b,s)$, are regressed against the integrating sphere band weighted radiance level, $L_\lambda(b,s)$, per the calibration equation:

$$Q(d,b,s) = G(d,b) L_\lambda(b,s) + B(d,b)$$

The slopes of these regression lines are the responsivities or gains, (G(d,b), and the intercepts are the biases, B(d,b). The Landsat Project Science Office is reviewing the various integrating sphere calibrations and their effective transfer to the ETM+ sensor before deciding which calibration should be provided to the IAS to populate the pre-launch IAS database.

Pre-Launch Radiometric Calibration: Thermal Band Calibration. The radiometric calibration of band 6, the thermal band, fundamentally differs from the reflective bands as the instrument itself contributes a large part of the signal. A model of this temperature-dependent instrument contribution has been developed by Raytheon Santa Barbara Remote Sensing. The calibration for band 6 is formulated as:

$$Q_{sc} - Q_{sh}(d) = G(d)(L_{\lambda,sc} - L_{\lambda,esh})$$

Where:

$Q_{sc}(d)$ is the quantized response of band 6 detector d to the scene,

$Q_{sh}(d)$ is the quantized response of band 6 detector d to the shutter,

$G(d)$ is the gain of detector d

$L_{\lambda,sc}$ is the spectral radiance of the scene

$L_{\lambda,esh}$ is the scene-equivalent spectral blackbody radiance of the shutter:

$$L_{\lambda,esh} = L_{sh} + \Sigma a_j (L_{sh} - L_j)$$

where L_{sh} is the blackbody radiance of the shutter, L_j is the blackbody radiance of the jth component of the ETM+ instrument, and a_j is the emissivity adjusted view factor for the jth ETM+ component of the
j = 1 for scan line corrector; j = 2 for the central baffle;
j = 3 for the secondary mirror and mask; j = 4 for the primary mirror and mask; j = 5 for the scan mirror. Each of these components is in front of the shutter and contributes to the apparent scene radiance when the shutter is open.

The pre-launch calibration of band 6 is primarily a calibration of this model. The radiometric calibration of the thermal band occurs during thermal vacuum testing. During this test, the ETM+ sensor is aligned to the thematic mapper calibrator (TMC), a collimator with selectable sources at its focus. During the band-6 calibration, blackbody sources are used in the TMC. The band-6 detectors' responses to combinations of various TMC blackbody and instrument temperatures are used to calibrate the instrument and to refine emitted radiance contributions from various internal ETM+ components. The results of this calibration are nominal gains and biases for band 6 and the emissivity-adjusted view factors (a(j)) for the various internal components of the ETM+ sensor that affect the band-6 calibration. The gains and biases are included in the calibration parameter file as pre-launch values for band 6.

Tolerance:
Pre-launch information, followed by post-launch information, is pending.
Frequency of Calibration:
After launch, the ETM+ sensor's response is examined on a regular basis. Occasionally, ground-look calibrations also are performed.

Other Calibration Information:
Post-Launch Radiometric Calibration. The post-launch radiometric calibration of the ETM+ sensor is accomplished by regularly examining the instrument's response when illuminated by known sources that are relatively stable. The ETM+ sensor has three onboard calibration devices, including the internal calibrator (IC), the partial aperture solar calibrator (PAC), and the full aperture solar calibrator (FAC). The IC is useful for calibrating all ETM+ sensor bands, while the PAC and FAC are mainly useful for calibrating the reflective bands. Ground-look calibrations are occasionally performed to confirm, via independent analyses, the accuracy of the calibration using onboard sources.

Internal Calibrator. The IC consists of a shutter flag, two tungsten lamps, and a blackbody source. When the ETM+ sensor is operating, the IC's shutter flag oscillates in synchronization with the sensor's scan mirror. The size of the shutter flag and its speed of movement combine to provide obscuration of the light to each detector for about 8.2 milliseconds or 750 pixels for the 30-meter channels. The light pulse for the reflective bands has a width of approximately 40 pixels. For band 6, the calibration signal is similar with the blackbody pulse being about 20 pixels wide.

Full Aperture Solar Calibrator. Sensor image data acquired with the FAC appear to be an essentially flat field with vignetted cross-track edges. The image increases in brightness in the along-track direction as the solar zenith angle on the panel decreases. Specifications require the FAC to fill the ETM+ sensor's aperture for the central 1,000 pixels (approximately 1/6 of each scan line). The design nominally fills the aperture for approximately the central 50 percent of the scan line. As the mirror scans, the view angles to the FAC panel change. If the nadir-viewing pixel has the nominal 23.5-degree view angle and a 0-degree view azimuth angle, then at the extreme ends of the scan, the view zenith angle increases by about 1 degree and the view azimuth angle varies by about ±30 degrees. Pre-launch measurements of the bidirectional reflectance distribution function indicate that the radiance change across the scan should be a 1-percent effect across the full scan, assuming the aperture is filled. Across the central 1,000 pixels, this translates into a 0.1-percent effect.

Partial Aperture Solar Calibrator. The PAC is used for calibrating bands 1 through 5, 7, and 8 and consists of a small passive device that allows the ETM+ sensor to image the Sun while viewing the darker Earth. Measurements of the alignment between the PAC and the scanner assembly have revealed a design misalignment, which resulted in a nominal declination angle of the PAC (relative to satellite nadir) of 20 degrees versus the prescribed 18 degrees. This increase in declination effectively forces the satellite to acquire scenes earlier in its orbit (i.e., closer to satellite sunrise). Although the satellite's solar panel undergoes a period of thermal instability during sunrise, an analysis of the resultant jitter has shown minimal impact (< 1 percent) to the acquisition of PAC data.

The PAC generates a reduced-resolution image of the Sun, because the resolution is limited by diffraction from the small apertures. Within a PAC-processed image, it is anticipated that most uniform portions of the Sun's center will be approximately 200 pixels in width for bands 1 through 5 and for band 7, 105 pixels for band 6, and 410 pixels for band 8. Calibration is performed once a day, every day, on an orbit specified by the IAS.

Specifications:
Pre-Launch Geometric Calibration. The IAS is designed to perform four types of geometric characterization for verifying and monitoring system geometric performance. The IAS also is designed to perform three types of geometric calibration for estimating improved values for key system geometric parameters.

Geometric characterizations include:
Geodetic accuracy assessment for measuring the absolute accuracy of systematically corrected (level-1G) products. Geometric accuracy assessment for qualitatively evaluating residual internal geometric distortions with level-1G images. Band-to-band registration assessment is used for measuring and monitoring the relative alignment of the ETM+ sensor's eight spectral bands. Image-to-image registration assessment for measuring and monitoring the accuracy of multitemporal image registration.

Geometric calibrations include:
Sensor alignment calibration for providing information on the geometric relationship between the ETM+ sensor's optical axis and the Landsat-7 satellite's attitude control reference system. Scan mirror calibration for measuring and correcting systematic deviations in the ETM+ sensor's scan mirror along- and across-scan profiles. Focal plane calibration for measuring and providing estimates of the eight band center locations on the ETM+ sensor's two focal planes relative to the sensor's optical axis.

Techniques for measuring and estimating improved values for individual detector locations and delays are being researched and may be added as a post-launch capability.

Frequency of Calibration:
Geometric calibration is performed during the Initial On-orbit Checkout period. Additional calibrations are performed on a quarterly basis or periodically as needed.

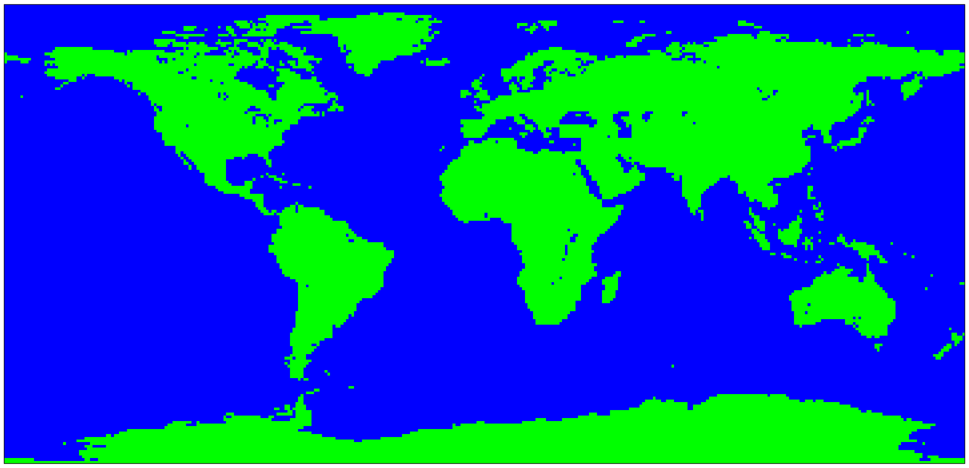
Other Calibration Information:
Geometric Calibration: Initial On-orbit Checkout Period. The most critical geometric calibration activities involve measuring and verifying sensor system performance during the checkout period, using geodetic, geometric, band-to-band, and image-to-image characterizations, as well as performing the initial sensor alignment calibration. In addition, it may be necessary to update the pre-launch focal plane (particularly band placement) and scan mirror profile calibrations. The results of these calibration activities are used to verify that the system is performing within specifications and are used to create an initial post-launch release of the calibration parameter file.
Geometric Calibration: Post-Checkout Calibrations. After the initial checkout period, ongoing calibration activities include monitoring the stability of the sensor system's geometric performance and attempting to identify and characterize systematic variations in the system's geometric parameters. Sensor alignment calibration is designed to improve in-flight knowledge of the relationship between the sensor and satellite navigation. The IAS is required to estimate sensor alignment to 24-arc-second accuracy (per axis) at least once per calendar quarter. In performing periodic checks, it may be determined that alignment knowledge has changed enough to warrant generating an updated sensor alignment matrix for inclusion in the calibration parameter file.

The behavior of the ETM+ sensor's scan mirror is measured and calibrated as necessary, using the IAS scan mirror calibration capability. The calibration process includes comparing a terrain-corrected image to a high-accuracy reference image that is constructed from a higher resolution source in order to detect systematic deviations in scan mirror motion from its nominal profile. Significant deviations are put in the calibration parameter file as updates to the scan mirror's profile polynomial coefficients. Scan mirror calibration applies to both along- and across-scan directions in order to detect and compensate for scan line corrector deviations as well. In practice, scan line corrector deviations are indistinguishable from scan mirror deviations so scan line corrector deviations are modeled as part of scan mirror motion. Distortions from many scans are analyzed to detect systematic deviations from the pre-launch forward and reverse scan mirror profiles.

5. Preparation and Description:
Data Description:
Spatial Characteristics:

Landsat-7 data are collected from a nominal altitude of 705 kilometers in 183-kilometer swaths, providing global coverage.
Spatial Coverage:
Platform: Near-polar orbiting system
Sensor:
Latitude coverage--81 degrees north to 81 degrees south
Longitude coverage--180 degrees east and west

Spatial Coverage Map:



Spatial Resolution:
The following table on band characteristics contains information on spatial resolution.

Table 5. Landsat-7 ETM+ Band Characteristics

Band Number	Spectral Range (m)	Ground Resolution (m)	Data Lines Per Scan	Data Line Length (bytes)	Bits Per Sample
1	.450 to .515	30	16	6,600	8
2	.525 to .605	30	16	6,600	8
3	.630 to .690	30	16	6,600	8
4	.775 to .900	30	16	6,600	8
5	1.550 to 1.750	30	16	6,600	8
6*	10.40 to 12.50	60	8	3,300	8
7	2.090 to 2.35	30	16	6,600	8
8	.520 to .900	15	32	13,200	8

- Values apply to both high and low gain data.

Projection:
During processing, level-0R image data undergo two-dimensional resampling, according to user-specified parameters. These parameters include output map projection, rotation angle, pixel size, and resampling kernel. Following are the eight NASA-supported map projections:

Lambert Conformal Conic
Oblique Mercator A
Oblique Mercator B
Polar Stereographic
Polyconic
Space Oblique Mercator
Transverse Mercator
Universal Transverse Mercator

Temporal Characteristics:
Temporal Coverage:
Temporal coverage is guided by the Landsat-7 mission's Long-Term Acquisition Plan (LTAP), designed to identify acquisition requirements for the Landsat-7 satellite system. An outgrowth of recommendations from the

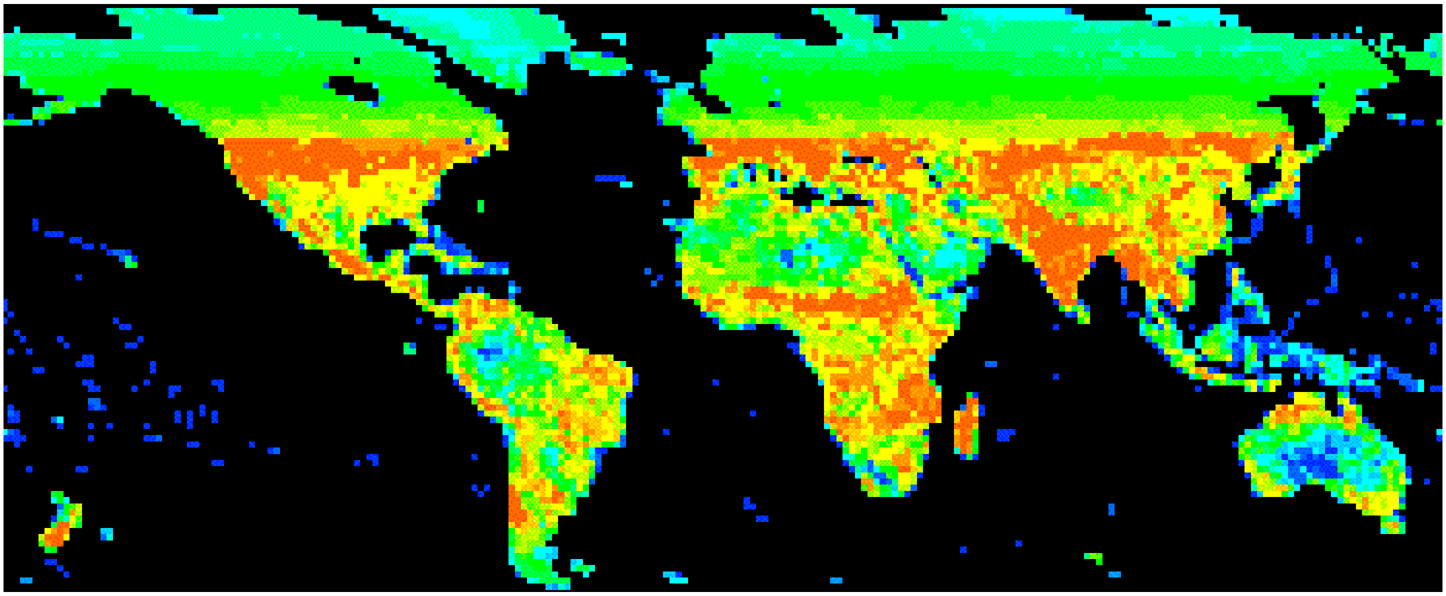
scientific community, the purpose of the LTAP is to optimize the use of the Landsat ETM+ sensor to create an archive of data that documents the processes on the Earth's land surfaces.
The Landsat-7 satellite's collection criteria are based upon the LTAP's acquisition strategy, including:

1. Seasonality. The plan is to record the annual cycle of vegetation dynamics over the life of the Landsat-7 mission, creating an archive that can be used to evaluate vegetation distribution and changes in vegetation.
A priority of the LTAP is to document change. For example, areas with a history of significant change are assigned many acquisitions (see areas in red on temporal coverage map) while areas with a history of lesser change are assigned fewer acquisitions (see areas in blue on temporal coverage map). Areas of high latitude also are assigned fewer acquisitions, because of Sun-angle constraints.

2. Cloud Conditions. Predicted cloud conditions originate from NOAA and consist of percentages of cloud cover derived from forecasts prior to acquisition. The predictions of NOAA are compared with cloud climatology derived from the International Satellite Cloud Climatology Project (ISSCP) data set for each WRS scene. If NOAA's predicted cloud cover is lower than the ISSCP-generated cloud cover threshold, then the acquisition priority for that particular WRS scene is increased.

3. Gain Settings. For pending WRS scenes which are designated for acquisition by both the seasonality index and by cloud conditions, the per-band sensitivity of the ETM+ instrument is set by adjusting the gain to conditions expected for that particular location at that particular time of year. Examples of priorities that may override LTAP specifications include natural disasters, issues of national security, and specific user requests.

Temporal Coverage Map:



Annual Acquisition Pattern (Grades from Red Down to Blue.)

Temporal Resolution:
Each ETM+ sensor scan views the Earth for approximately 62 microseconds. During this period, each channel of the analog data output is digitized. Digitization varies from channel to channel. For the 30-meter resolution bands, approximately 101,120 samples are obtained per scan. Successive scans occur at the rate of about 16 scans per second. Subsequent coverage of the same geographic area occurs nominally every 16 days. However, Landsat-7 data collection is driven by the LTAP (described above).

Data Characteristics:
Parameter/Variable:

Level 0. Landsat-7 output files are comprised of numerous parameters and formats as described in the "Landsat 7 System Zero-R Distribution Product, Data Format Control Book, Volume 5, Book 1, Revision 2," dated July 1998 (see References). Following is an overview of 23 full-band, level-0, WRS-scene product files as derived from the Landsat-7 system's wideband telemetry, an IAS-generated calibration parameter file, a product-specific metadata file, an Earth Observing System Data and Information System (EOSDIS) EOSDIS Core System (ECS)-generated geolocation index, and an heirarchical data format (HDF) directory file. For detailed information concerning file contents, formatting, data types, and descriptions, see the Code Book.

Variable Description/Definition:
Earth image data. Data are collected by the Landsat ETM+ sensor in eight bands (see Spatial Resolution) with band 6 being collected in both high- and low-gain modes.

Internal calibrator data, format 1. Internal lamp and shutter data are collected in order by scan (low gain). Data are collected in band sequential format once per scan and are collected in descending detector order for the 30-meter bands. Internal calibrator data, format 2. Internal lamp and shutter data are collected in order by scan line for bands 7 and 8 while blackbody radiance and shutter data are collected for band 6 (high gain). Data are collected in band sequential format once per scan and are collected in descending detector order for the 30-meter bands.

Calibration parameters. The IAS regularly updates the calibration parameter file, because of changing radiometric and geometric parameters required for level-1 processing. These calibration parameters are included with level-0 products. Mirror scan correction data, MSCD format 1. An MSCD logical record consists of three data values as they apply to the immediately preceding scan line. The three data values include scan error for the first half of the data scan, scan error for the second half of the data scan, and the direction of the scan line. This information is used to compute deviations from nominal scan mirror profiles as measured on the ground and reported in the calibration parameter file. An MSCD file also includes scan-based values such as time code, gain status, and processing errors as encountered by the Landsat Processing System (LPS). The MSCD files are modified by product with an extra file added during the subsetting process, because of the file's correspondence to the previous scan.

Mirror scan correction data, MSCD format 2. A duplicate set of MSCD values are generated during format-2 processing in the event that format-1 data are lost or corrupted.

Payload correction data, PCD format 1. A PCD file includes attitude and ephemeris profiles and high-frequency jitter measurements. The information in a PCD file is distributed in subinterval increments no matter what the coverage of individual products.

Payload correction data, PCD format 2. A duplicate set of PCD values are generated during format-2 processing in the event that format-1 data are lost or corrupted.

Scan line offsets, format 1. During LPS processing, image data are shifted in an extended buffer to account for predetermined detector and band shifts, scan line length, and possible bumper wear. The scan line offsets represent actual starting and ending pixel positions for valid or nonzero-filled image data on a data-line-by-data-line basis for bands 1 through 5 and for band 6 at low gain. The left-starting pixel offsets apply to both image data and internal calibration data, while the right-hand offsets for image data and for internal calibration data differ and are reported separately.

Scan line offsets, format 2. As with format-1 image data, format-2 image data are shifted in an extended buffer to account for predetermined detector and band shifts, scan line length, and possible bumper wear. The scan line offsets represent actual starting and ending pixel positions for valid or nonzero-filled image data on a data-line-by-data-line basis for band 6 at high gain and for bands 7 and 8. The left-starting pixel offsets apply to both image data and internal calibration data, while the right-hand offsets for image data and for internal calibration data differ and are reported separately.

Metadata, format 1. During LPS processing, metadata are generated for each subinterval's spatial extent, content, and data quality for bands 1 through 5 and for band 6 at low gain. These metadata are distributed in their original form and in their entirety.
Metadata, format 2. During LPS processing, metadata are generated for each subinterval's spatial extent, content, and data quality for band 6 at high gain and for bands 7 and 8. Format-2 metadata do not include cloud cover assessments or references to browse data. These metadata are distributed in their original form and in their entirety.
Metadata, ECS. During order processing, ECS generates a third metadata file. This file contains product-specific information such as corner coordinates and the number of scans.

Geolocation index. This ECS-generated table contains scene corner coordinates and product-specific scan line numbers for bands 1 through 8, covering all three band resolutions.

HDF directory. The directory contains the pointers, file-size information, and data objects required to open and process level-0 products, using the HDF library and interface routines. Every level-0 product includes two PCD files, two MSCD files, three metadata files, the calibration parameter file, and the HDF directory. Counts for internal calibrator, scan line offset, and image files are affected when products contain less than the full complement of bands.

Level 1. The HDF full-band, level-1 product file format is nearly identical to the full-band, level-0 product file format except that the two MSCD files have been merged and the two PCD files have been merged. The merging of the files is referred to as consensus. In addition, the metadata contain level-1 correction information. For more information, refer to the "Earth Science Data and
Information System (ESDIS) Level 1 Product Output Files Data Format Control Book, Volume 5, Book 2, Revision 2," dated November 1998 (see References).

Unit of Measurement:
Level 0. Landsat-7 level-0 data are in their raw form. Calibration parameters, though provided in the parameter calibration file, are not applied.
Level 1. W/(m2 sr µ)
Data Source: The Landsat ETM+ sensor flown aboard the Landsat-7 satellite.
Data Range: The radiance values reported in the nine respective band files are quantized to 8-bit DN, reflecting 256 levels of radiance.

Sample Data Record:
Information on the numerous data records is available in the "Landsat 7 System Zero-R Distribution Product, Data Format Control Book, Volume 5, Book 1" and in the "Earth Science Data and Information System (ESDIS) Level 1 Product Output Files Data Format Control Book, Volume 5, Book 2" (see References).

Data Organization:
Data Granularity:
A general description of data granularity as it applies to the EOS Data Gateway appears in the EOSDIS

Glossary.

Worldwide Reference System (WRS) Scene. Landsat-7 ETM+ sensor data are framed into approximately 183-kilometer by 170-kilometer increments or scenes. The nominal centers for the Landsat-7 scenes map to the WRS reference system used for Landsat-4 and -5 data. Therefore, the scenes are referred to as WRS scenes.

Interval. An interval is described as the duration of time between the start and the end of an imaging operation or land observation by the ETM+ sensor. The raw wideband data collected during an interval consist of a contiguous set of WRS scenes not to exceed the length of 90 scenes.

Subinterval. In general, a subinterval is a segment of an interval. Subintervals are the result of breaks in the wideband data stream. These breaks may be due to communication dropouts, due to the inability of the Landsat-7 spacecraft to transmit a complete observation or interval within a single contact period, or due to both of these circumstances. The smallest subinterval equates to a partial EMT+ scene, which also may be referred to as a subscene, while the largest subinterval may not exceed the length of 35 WRS scenes.

Partial Subinterval. A partial subinterval is a segment of a subinterval, no less than the length of one WRS scene and no more than the length of 35 WRS scenes, the maximum length of a subinterval. A partial subinterval may be positioned at the starting point of any scan line and may be defined by either contiguous WRS locations or by rectangular latitude and longitude bounding coordinates. In the latter case, all scan lines touched by the bounding rectangle are included in their entirety.

Currently, data are distributed at the single WRS-scene granule level. Distribution of subintervals and partial subintervals is pending.

Data Format:
Level 0. Hierarchical Data Format (HDF). Standard HDF structures are used. Landsat-7 level-0 product HDF data structures include: one data type.
Vdata: A record-based structure where values are stored in fixed-length fields. Fields are individually defined, named, and typed. All records within a Vdata are identical in structure.
Vgroup: A structure for associating sets of data objects. Vgroups define logical relationships and may contain any HDF objects, including other Vgroups.
External Element: Data stored in a separate file that is external to the basic HDF file. External elements allow for larger product sizes and provide the capability to read level-0 products without using the HDF library. Information about the HDF structure and interrelationships of external elements may be found in the HDF directory.

Level-0 files and external elements may vary by product size. The files accompanying each full-band, dual-format, level-0 product include: the HDF directory (containing the pointers, file-size information, and data objects required to open and process level-0 products, using the HDF library and interface routines), two payload correction data files (format 1 and format 2), two mirror scan correction data files (format 1 and format 2), three metadata files (format 1, format 2, and ECS specific), a calibration parameter file, and a geolocation index.

Data may be represented in both binary and American Standard Code for Information Interchange (ASCII) formats. Bit and byte ordering follow conventions set by the Institute of Electrical and Electronics Engineers with the term "byte" being synonymous with octet as used by the International Organization for Standardization. More HDF information may be viewed at the HDFinfo Web site.

File Naming Convention. Level 0. Except for the calibration parameter file, level-0 HDF data structure names are derived as follows:
L7XsssfnYYDOYHHuuv_xxx.DOYxxxx
where

L7 indicates the Landsat-7 mission.
X indicates the Landsat-7 X-band used to downlink data to the Landsat ground station.

1 = XL (low frequency)
2 = XM (medium frequency)
3 = XH (high frequency)

This is the normal mapping of the numerical value of the capture source in the configuration table. For files received on tape from Alaska or Norway, the current value of the string is used unless specified otherwise.
sss indicates the ground station.
AGS = Pojer Flat, Alaska.
EDC = U.S. Geological Survey's EROS Data Center, Sioux Falls, South Dakota.
IGS = International ground station. This identifier is used for tapes received from downlink sites other than the sites mentioned in this list.
SGS = Svalbard, Norway.
f indicates ETM+ data format.
n indicates an LPS processor number (1-9).
YY indicates the last two digits of the year associated with a contact period (not acquisition time).
DOY indicates the Julian date for the contact period.
HH indicates the hour of the contact period within a 24-hour day (00-23).
uu indicates a subinterval number within this contact period (01-99).
v indicates the data set version number (v = 0 for original data or 1-9 for reprocessed data).
xxx indicates the type of data (MSD for mirror scan correction data, PCD for payload correction data, GEO for the geolocation index, B10 through B83 for the image data, C10 through C80 for the internal calibration data, and O10 through O83 for the scan line offsets. The LPS uses the B81, B82, and B83 extensions for band 8 when multiple files are required for storage. The HDF data structure name starts with B81 even if band 8 is extracted from the second (B82) or the third (B83) LPS band-8 file. Similar naming conventions are used when naming scan-line-offset data objects.
DOY indicates Julian date for product creation.
xxxx indicates unique ECS 4-digit identifier.
Calibration parameters are stored as ASCII text using an object data language syntax developed by the Jet Propulsion Laboratory. The naming convention for the calibration parameter file is derived from the file name assigned by the IAS and is annotated as follows:
L7CPFYYYYMMDD_YYYYMMDD_nn

where
L7 indicates the Landsat-7 mission.
CPF indicates that it is the calibration parameter file.
YYYYMMDD_YYYYMMDD indicates the starting and stopping year, month, and day of the CPF
nn indicates the incrementing number within a 90-day period (01-99).
Level 1. Hierarchical Data Format (HDF). Standard HDF structures are used with slight file modifications from level 0 for level-1R and level-1G products (see Data Characteristics). The Landsat-7 data files are stored separately from the HDF directory file, which contains the file names and pointers for the data files. The level-1R and level-1G image files are in absolute radiance units scaled to 16 bits and 8 bits, respectively.
File Naming Convention. Except for the calibration parameter file, level-1 HDF data structure names are derived as follows:

L7fppprrr_rrrYYYYMMDD_AAA.XXX

where
L7 indicates the Landsat-7 mission.
f indicates the ETM+ data format.
ppp indicates the starting path of the product.

rrr_rrr indicates the starting and ending rows of the product.
YYYYMMDD indicates the acquisition date of an image.
AAA indicates the file type:

B10 = band 1
B20 = band 2
B30 = band 3
B40 = band 4
B50 = band 5
B61 = band 6L (low gain)
B62 = band 6H (high gain)
B70 = band 7
B80 = band 8
CAL = internal calibrator (1R only)
GEO = geolocation (1R only)
HDF = HDF directory file
MSD = consensus MSCD (1R only)
MTA = LPS metadata (1R only)
MTL = LPGS metadata
PCD = consensus PCD (1R only)
SLO = scan line offset (1R only)

xxx indicates the product type (L1R or L1G).

Calibration parameters are stored as ASCII text using an object data language syntax developed by the Jet Propulsion Laboratory. The naming convention for the calibration parameter file is derived from the file name assigned by the IAS and is annotated as follows:

L7CPFYYYYMMDD_YYYYMMDD_nn

where
L7 indicates the Landsat-7 mission.
CPF indicates that it is the calibration parameter file.
YYYYMMDD_YYYYMMDD indicates the starting and stopping year, month, and day of the CPF.
nn indicates the incrementing number within a 90-day period (01-99).
Level 1. FAST-L7A Format. Only radiometrically and geometrically corrected data (level-1G products) are available in the FAST-L7A format. The FAST-L7A product consists of header files and linked image files.

Header File
Administrative Record: Contains information that identifies the product, the image, and the data specifically needed to ingest the imagery for each particular band. In order to import the image data, it is necessary to read the entries in the administrative record.

Radiometric Record: Contains the coefficients needed to convert the image values into at-satellite spectral radiance for each particular band.

Geometric Record: Contains geodetic location information. To align the imagery to other data sources, it is necessary to read the entries in the geometric record for each particular band.

A separate header file exists for each of the following band groups:
1.Panchromatic

2.Visible Near Infrared/Shortwave Infrared (VNIR/SWIR)
3.Thermal

Image File

Each image file contains one ETM+ band of image pixels. There are no header records, prefix data, or suffix data in the image records. Image data are unblocked, and image files are 8-bit unsigned integers.
File Naming Convention. The file naming convention for FAST-L7A is as follows:
L7fppprrr_rrrYYYYMMDD_AAA.FST

where
L7 indicates the Landsat-7 mission.
f indicates the ETM+ data format.
ppp indicates the starting path of the product.
rrr_rrr indicates the starting and ending rows of the product.
YYYYMMDD indicates the acquisition date of an image.
AAA indicates the file type:
HPN = panchromatic band header file
HRF = VNIR/SWIR bands header file
HTM = thermal bands header file
B10 = band 1
B20 = band 2
B30 = band 3
B40 = band 4
B50 = band 5
B61 = band 6L (low gain)
B62 = band 6H (high gain)
B70 = band 7
B80 = band 8
FST indicates the FAST-L7A file extension.

Level 1. Geographic Tagged Image File Format (GeoTIFF). Only radiometrically and geometrically corrected data (level-1G products) are available in the GeoTIFF format. The GeoTIFF format defines a set of public domain TIFF tags that describe all of the cartographic and geodetic information that is associated with geographic TIFF imagery. The GeoTIFF format is used as a means for tying a raster image to a known model space or map projection and for describing the projection. A TIFF file makes it possible to encode both metadata and image data into the same file.
Each band of Landsat-7 data in the GeoTIFF format is delivered as a grayscale, uncompressed, 8-bit string of unsigned integers. No other files accompany the product.
File Naming Convention. The file naming convention for GeoTIFF is as follows:
L7fppprrr_rrrYYYYMMDD_AAA.TIF

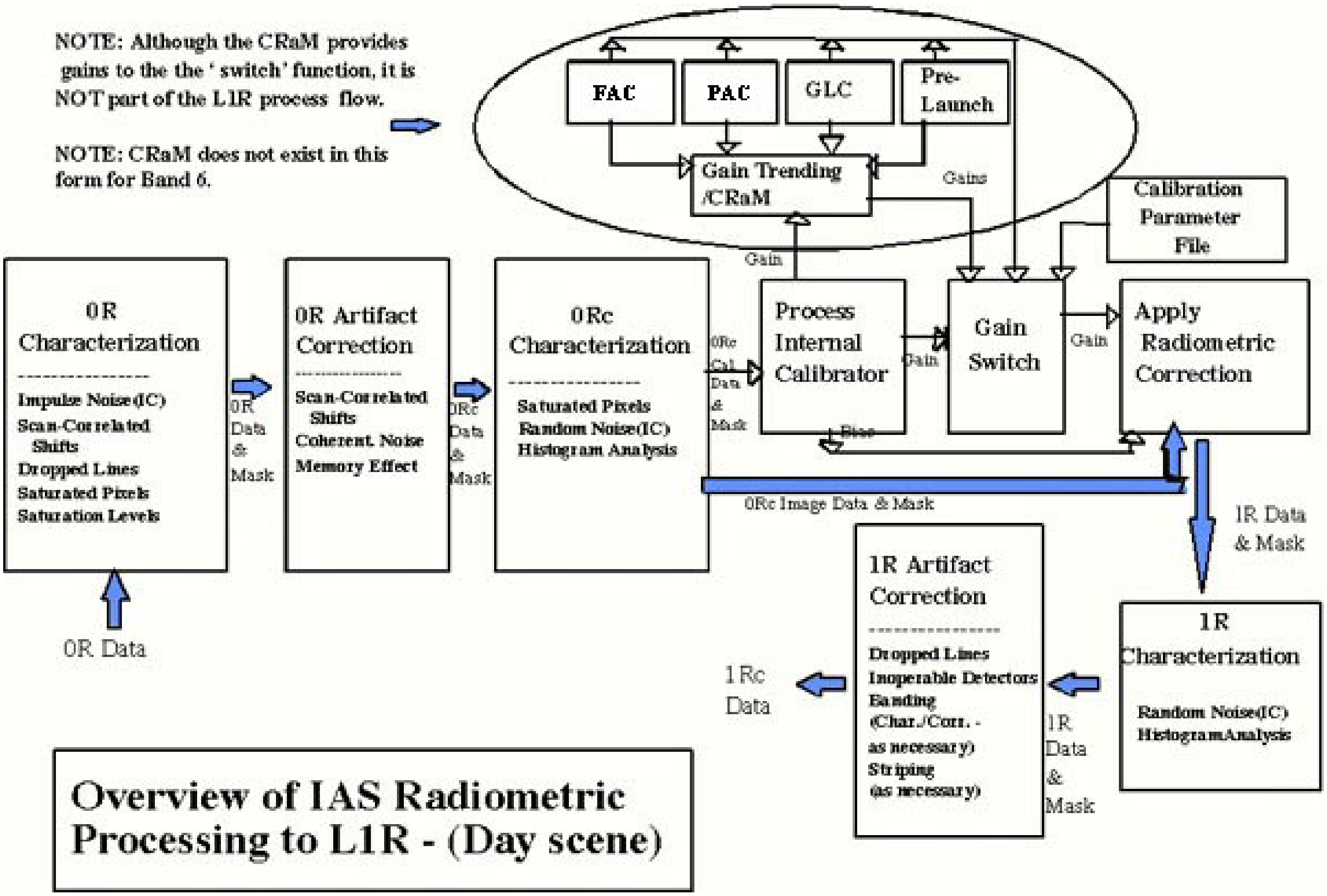
where

L7 indicates the Landsat-7 mission.
f indicates the ETM+ data format (1 or 2).
ppp indicates the starting path of the product.
rrr_rrr indicates the starting and ending rows of the product.
YYYYMMDD indicates the acquisition date of an image.
AAA indicates the file type:
B10 = band 1

B20 = band 2
B30 = band 3
B40 = band 4
B50 = band 5
B61 = band 6L (low gain)
B62 = band 6H (high gain)
B70 = band 7
B80 = band 8
TIF indicates the GeoTIFF file extension.
For more information on level-1 file formats, refer to the "Earth Science Data and Information System (ESDIS) Level 1 Product Output Files Data Format Control Book, Volume 5, Book 2, Revision 2," dated November 1998 (see References).
Data Manipulations:
Formulae:
Derivation Techniques and Algorithms:
Numerous radiometric and geometric algorithms apply to Landsat-7 data. See the Image Assessment System Web site for information on radiometric and geometric algorithms.
Data Processing Sequence:
Processing Steps:
Level 0. Landsat-7 level-0 data are defined as raw data. Level-0R products are generated directly from the wide-band microwave signal received from the Landsat-7 satellite. Other than decoding and separating the data into files, the only data processing or data manipulation is the application of gains and biases for removing instances of striping and banding. The values for these gains and biases are contained in the calibration parameter file. If data in their original format are required, the gain and bias values may be removed.

Level 1. Radiometric Processing. Radiometric processing of ETM+ sensor data occurs within two segments of the Landsat-7 ground system, the Image Assessment System (IAS) and the Level-1 Product Generation System (LPGS). The IAS is responsible for generating the calibration data while the LPGS is the United States production facility. The goal is for both segments to use the same data-processing algorithms, although the LPGS does not have the flexibility of the IAS, nor does it generate all of the ancillary output.

Radiometric processing for Landsat-7 data differs in several ways from the previous Landsat systems. The first difference is the existence of an offline system responsible for generating calibration parameters and for evaluating data quality. The second difference is the ability to characterize and correct for various radiometric artifacts in the data prior to calibration. The third difference is the capability to rely on data acquired outside of the current scene being processed to perform the calibration, due in part to the addition of the new calibration hardware and due in part to a change in philosophy.
The figure below illustrates the overall flow in the radiometric processing of a level-1R product (i.e., the radiometrically, but not geometrically corrected product). The process is divided into five elements:
1. Radiometric characterization of the 0R product.
2. Correction of radiometric artifacts (where the mechanism is understood).
3. Characterization of the data after artifact correction (0Rc).
4. Determination of and application of the calibration.
5. Post application characterization and cosmetic fixes for unsuccessfully corrected artifacts.



The 0R data product, which consists of uncalibrated image data, internal calibration data, payload correction data, and metadata, is ingested by the IAS. On ingest, instrument status data, including times and temperatures, are extracted from the payload correction data for the scene to be processed and for surrounding scenes in the data collection interval. These temperature data are checked for outliers and fitted versus time to provide values for the scans in the scene being processed.

At 0R characterization, the internal calibration data are checked for impulse noise detector by detector, using an along-scan median filter. Scan-correlated shifts are located (i.e., bias changes occurring in all detectors simultaneously between scans as observed on Landsat-4 and -5 TM sensor data). Fill data that were inserted at locations where data were lost in transmission are located, and pixels at the bounds of the analog-to-digital (A/D) converter are flagged (i.e., normally, pixels with 0 or 255 values). The locations of the impulse noise in the calibrator data, the filled data, and saturated pixels are placed in a mask that becomes associated with the data throughout level-1R processing. The mask contains the location and the type of artifact found in the data (e.g., dropped lines, impulse noise, A/D saturation, analog saturation).

Histograms of the data are checked for evidence of saturation of the A/D converter at other than the nominal 0 and 255 values. The results of the characterizations are reported and stored in a data base for trending and evaluation. The 0R data continue to the artifact-correction stage. At this stage, the image data are merged in time sequence with the internal calibrator data to reconstruct the data as originally generated by the instrument. Depending upon the presence and magnitude of the artifacts in the ETM+ sensor data, up to three corrections are performed. First, the scan-correlated shifts are removed by adding the bias into the scans where the shift occurred. And second, coherent noise is filtered out by either notch filtering or time-domain addition of an oscillating signal to the data. The TM sensor did not exhibit sufficiently well-behaved coherent noise (i.e., stability in frequency or phase) to remove coherent noise by the additive method. In the process of performing these corrections, the mask is used to ignore data that are filled, saturated, or noisy from determining the correction factors. After the corrections are applied, the data are referred to as 0Rc. The calibration and image data are separated for the next stage of processing. The 0Rc data undergo additional radiometric characterization. If it is determined that the analog portion of the ETM+ sensor's signal chain saturated before the A/D converter, pixels exhibiting this saturation are found and flagged in the labeled mask. An analysis of the dark region of the shutter is performed to characterize the noise present and its randomness. The noise results are reported and trended. This serves as a portion of the check for detector operability. Histograms of the 0Rc data are analyzed on a detector-by-detector basis to provide relative gains between the detectors in a band. These gains are reported and trended and can be used in the correction process to adjust the gains applied during application of the radiometric calibration. At this point, the 0Rc calibration data proceed to the process internal calibrator. Within the process internal calibrator, gains and biases are generated on a detector-by-detector basis. The process internal calibrator also checks for dead detectors. These gains are passed along in the flow and are sent to a data base where they are trended, fitted, and eventually combined with the results from other calibrators using a combined radiometric correction model (CRaM). Prior to starting radiometric processing, a switch is set that determines which gain is to be applied to the image. Choices include: (1) the gain calculated from the internal calibrator using the scene, (2) the gain values in the current calibration parameter file, (3) the current output of the CRaM, and (4) the current trended values of the gains from any calibrator, including FAC, PAC, ground look, IC (either lamp), and the pre-launch calibration parameter file. Part of the gain switch also includes whether or not a relative gain correction is applied to the data, using the relative gains from histogram analysis or a trended data base value. The gain values are then applied to the image data and calibration data to convert the data to real radiance values. The output at this stage is level 1R.

The level-1R product is characterized, using histogram analysis for residual striping, and the random-noise analysis is repeated. If the product proceeds to geometric processing, missing data and data that are dead or inoperable (severely degraded) are filled in or left alone. Whether the data are filled in or left alone depends upon how a flag is set. Based upon:

1. how an operator sets a flag
2. the results of the histogram analysis for striping
3. a banding analysis

A destriping algorithm, a debanding algorithm, or both algorithms may be performed to cosmetically improve the data if deemed necessary.

Level 1. Geometric Processing. Pending.

Calculations: Special Corrections/Adjustments:

The IAS periodically updates the parameter calibration file, based upon changes in radiometric and geometric calibration.

Calculated Variables: Scene center and scene corner points are approximated for archiving and cataloging purposes. The approximated points are derived from the parameter calibration file.

Errors: Sources of Error: Pending.

Quality Assessment: Data Validation by Source: Pending.

Confidence Level/Accuracy Judgment: Pending.

Measurement Error for Parameters: Pending.

Additional Quality Assessments: Pending.

Data Verification by Data Center:

The IAS, an element of the Landsat-7 ground segment, is responsible for off-line assessment of image quality in order to ensure compliance with the radiometric and geometric requirements of the spacecraft and the ETM+ sensor throughout the life of the Landsat-7 mission.

6. Notes and Plans:

Limitations of the Data: Pending.

Known Problems with the Data:

Analyses performed on Landsat-5 data over the years have revealed the existence of imperfections or image artifacts caused by a variety of factors (e.g., the instrument's electronics, dead or dying detectors, downlink

errors). The ETM+ sensor may have some, all, or none of the TM sensor's artifacts or other new artifacts. Testing is in progress and available of results is pending.
Usage Guidance:
The remotely sensed satellite data collected by the Landsat ETM+ sensor is similar to the data collected by previous Landsat satellites and may be used for similar applications.

Future Modifications and Plans:

The Earth Observer-1 (EO-1), the first satellite in NASA's New Millennium Program, is scheduled to be flown in the year 2000 with an orbit that is complementary to that of the Landsat-7 satellite. The mission of the New Millennium Program is to develop and validate instruments and technologies for gathering observations that are currently unavailable through spaceborne platforms and instruments. The testing of this advanced technology may have a broad impact on future land imaging missions and on the development of future satellite systems, including the Landsat series (i.e., planning continues for a Landsat follow-on mission).

7. Products and Access:
Contact Information: EDC DAAC User Services
Data Center Identification: EDC DAAC
Procedures for Obtaining Data:
These data are available through the EOS Data Gateway or by contacting EDC DAAC User Services.
Data Center Status/Plans: Fulfilling roles as the Distributed Active Archive Center for Land Processes and as the National Satellite Land Remote Sensing Data Archive, the U.S. Geological Survey's EROS Data Center will receive, archive, and distribute data from the Landsat-7 satellite.
Output Products and Availability:
The EDC DAAC distributes Landsat-7 level-0R (raw) data products as follows:
Media Types:
- 8-mm Tape
- File Transfer Protocol

Format:
- HDF

Coverage:
- WRS Scene
- Subinterval (availability pending)
- Partial Subinterval (availability pending)

The EDC DAAC distributes Landsat-7 level-1R (radiometrically corrected) data products as follows:
Media Types:
- 8-mm Tape
- Compact Disc
- File Transfer Protocol

Format:
- HDF

Coverage:
- WRS Scene
- Partial Subinterval (availability pending)

The EDC DAAC distributes Landsat-7 level-1G (radiometrically and geometrically corrected) data products as follows:
Media Types:
- 8-mm Tape
- Compact Disc
- File Transfer Protocol

Formats:

HDF
FAST L7A
GeoTIFF

Coverage:

WRS Scene
Partial Subinterval (availability pending)

The EDC DAAC distributes Landsat-7 calibration parameter files follows:

Media Types:

8-mm Tape
File Transfer Protocol

Formats:

ASCII Files

Coverage:

Temporal. Updated periodically.

Software:

Software Description:

A variety of public domain and commercial software tools are available for processing level-0R products in HDF or independent computing environments.

Software Access:

Information on the HDF, including reference manuals, user guides, release notes, newsletters, and source code, is available through the National Center for Supercomputing Applications HDF Group's Web site.

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9. Acronyms:

List of Acronyms:

A/D -- Analog-to-Digital
CRaM -- Combined Radiometric Correction Model
ERTS -- Earth Resources Technology Satellite
FAC -- Full Aperture Solar Calibrator (also FASC)
ECS -- EOSDIS Core System
EDC DAAC -- EROS Data Center Distributed Active Archive Center
EOS -- Earth Observing System
EOSDIS -- Earth Observing System Data and Information System
EROS -- Earth Resources Observation Systems
ETM+ -- Enhanced Thematic Mapper Plus
GeoTIFF -- Geographic Tagged Image File Format
GLIS -- Global Land Information System
HDF -- Hierarchical Data Format
IC -- Internal Calibrator
IFOV -- Instantaneous Field of View
IAS -- Image Assessment System
ISSCP -- International Satellite Cloud Climatology Project
LPGS -- Level-1 Product Generation System
LPS -- Landsat Processing System
LTAP -- Long-Term Acquisition Plan
MSCD -- Mirror Scan Correction Data
MSS -- Multispectral Scanner

NASA -- National Aeronautics and Space Administration
NOAA -- National Oceanic and Atmospheric Administration
PAC -- Partial Aperture Solar Calibrator (also PASC)
PCD -- Payload Correction Data
SBRS -- Santa Barbara Remote Sensing
SIS -- Spherical Integrating Source
SLC -- Scan Line Corrector
SME -- Scan Mirror Electronics
TM -- Thematic Mapper
TMC -- Thematic Mapper Calibrator
URL -- Uniform Resource Locator
USGS -- United States Geological Survey
WRS -- Worldwide Reference System
EOSDIS Acronym List

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